MAN IN SPACE

SCIENCE SERIES FOR THE YOUNG

Applied Science—2

About the Book

If exploration of the unknown is the stuff that dreams are made of, then surely space exploration is mankind's ultimate dream. Our generation had the privilege of witnessing the first steps in the pursuit of man's greatest adventure. That is what this book is all about. Starting with the single-orbit spaceflight of Yuri Gagarin, the author covers the evolution of U.S. and Soviet spaceflight capabilities. He then gives us an in-depth overview of Man's future activities around the home planet Earth—large space stations for research and study, solar power stations that will provide the entire electrical power requirements of large cities, telescopes to study the universe unhindered by our atmosphere, and a great deal more. Manned flights to other planets are advisedly left out of this book, and should form the subject of a future study.

A book for the young at heart of all ages.

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IBH

LISHING COMPANY
BOMBAY

First published: 1982

Phototypeset by Sterling Phototypesetters,
920 Tulsiani Chambers, 212 Backbay Reclamation,
Nariman Point, Bombay 400 021

Printed by D.G Mirchandani at IBH Printers,
Marol Naka, Mathuradas Vasanji Road,
Andheri East, Bombay 400 059

Published by P.C. Manaktala for IBH Publishing Company,
412 Tulsiani Chambers, 212 Backbay Reclamation,
Nariman Point, Bombay 400 021

ACKNOWLEDGEMENTS

The author would like to acknowledge with thanks the kind co-operation of the following for their valuable assistance in the production of this book.

The American Central Library, Bombay, for their assistance in obtaining the necessary reference material; SPAN magazine for the colour transparencies from their files; Dr.–Ing. Dieter Lennertz, Head of Earth Observation Programme, European Space Agency, for colour transparencies on the Space Shuttle and Spacelab; Mr. T.C. Bickerton, Public Relations Officer, British Aerospace Dynamics Corporation, for transparencies on the Space Telescope; Mr. F. Alexandrov, Chief Press Information Officer, USSR Embassy in India, for colour transparencies on Soviet space flight activities. Last but not the least, the author would like to thank Dr. S. Venkatavardan for having given so much of his valuable time to go through the manuscript, and for his numerous valuable suggestions.

H.P.MAMA

FOREWORD

Man's thirst for knowledge and adventure have taken him to the highest mountains and the deepest oceans. He has explored deserts of sand as well as snow, and flown faster and higher than any bird. Outer space represents Man's last great frontier.

It was our generation's good fortune to witness the dawn of the space age and the first attempt to set foot on a world other than our own. The footprints which were left behind by Neil Armstrong on the Moon will remain undisturbed for thousands of years — a lasting memorial to that historic event. Man is destined to explore and spread out into the Universe, the way he did on planet Earth many centuries back. He will first explore and, perhaps, colonise some of the planets of our own solar system. Mankind may then go to planets around other stars in our Milky Way galaxy and beyond, perhaps travelling at speeds close to that of light itself !

But despite all these achievements, Man's greatest activity will continue to be around his home planet, the Earth. That is what this book is all about.

Few men have had the privilege to venture into space to date, though their number will rapidly increase with time. But for millions of us, this great adventure has been brought into our living rooms through the marvel of television.

Manned spaceflight has raised a number of questions. Is it necessary for Man to go into space? Is it worth the cost and the risk? Could we achieve the same results through robots? What can we achieve in space and what do we hope to gain from it?

This book attempts to answer these and other related questions.

MAN'S FUTURE IN SPACE

WHY EXPLORE SPACE?

People often ask 'Why "waste" money on going into space when there is so much to be done on our own planet, Earth?' Similar questions were asked in the past about electricity, tele-communications, aircraft, and just about every other technical achievement of Man.

At one time, we could get along very well without electricity. Today, if the world's entire supply of electric power were suddenly to be switched off, our civilisation would collapse. That is because our civilisation has created some new requirements which were never thought of in the past.

At first sight, many scientific discoveries may have no apparent use for mankind. However, they often lead to applications and developments that did not exist previously. In the process, they usually help to enrich Man's life on Earth.

This brings us to our first question: 'Why waste money on exploring space?' Yes, why indeed?

This question was answered very ably by a former member of the U.S. Congress. He said:

> 'There was plenty to be done in Europe when Columbus left it in search for a new world. There is still plenty to be done there. But if Columbus had waited till Europe had no more internal problems, he would be waiting there still. On the other hand, the opening up of the New World did more to revive Europe's culture and economy than any international action could possibly have done.'

WHY SHOULD MAN GO INTO SPACE?

This brings us to another important question. Why should Man go into Space at such great cost and risk? Instead, can we not use robots, which are automated spacecraft?

Man is the most sensitive and delicate part of the space system. His presence places many limitations on the design of a spacecraft and considerably increases its weight, cost, and complexity. What favours Man's presence in space is his very exclusive quality: **intelligence**. Intelligence helps man to think independently in situations involving an infinite variety of unexpected problems. Machines designed to perform only limited functions accomplished by Man's intelligence can easily outperform him in those fields. On the other hand, **no** existing machine can handle **all** the functions of Man's highly versatile mind.

The brain can retain 100,000,000,000 items of information. By comparison, our most powerful computers can only hold a few million. Today a

Apollo 17 **Astronaut Roland Evans emerging from his spacecraft to retrieve the film from the Service Module during the return flight to Earth.**

machine with a memory capacity of Man's brain would occupy as much space as New York's Empire State Building. Some years back, it would have occupied about one-third of the area of India! It would still take about half the power output of Bhakra-Nangal Dam, and probably cost Rs.100,000,000,000. The computer's main advantage is its **speed.** It can calculate a hundred million times faster than the human brain.

On the other hand, today's computers have no power of reasoning for

themselves.

Returning to space exploration. small. unmanned satellites are adequate for simple and repetitive functions. Thus, these can easily measure data, and process and transmit them to Earth. The moment their functions begin to get complicated, Man comes into the picture. Man can use his unique skills and judgement while undertaking space research and exploration. He can observe unexpected events which an automated spacecraft would fail to understand or miss altogether.

Should some equipment go wrong, only Man would be able to repair it. The first U.S. Orbiting Astronomical Observatory, which had cost 50 million dollars, failed shortly after it was launched. So did some equipment on our own *Aryabhata* and *Bhaskara* satellites. A single technician in space could have repaired them and thus saved millions of rupees.

We all remember how the U.S. *Skylab* spacecraft, damaged in an accident during its take-off, was repaired by Astronaut **Charles Conrad Jr.**, and his crew with great effort and ingenuity, and at great personal risk. But for them, *Skylab* would have been a total failure.

What functions would Man be required to carry out in space? He would have to be there for operating complex equipment in space observatories, research laboratories, and similar set-ups. Man's presence will be even more essential for exploring the Moon and the planets. The knowledge gained from puny, automated spacecraft that took pictures of the Moon, or brought small soil samples, was utterly insignificant when compared to that gained from the manned *Apollo* lunar landings.

While the *Apollo* flights cost several times as much as all the U.S. and Soviet automated lunar spacecraft combined, their scientific value was greater in proportion to their cost. For a really detailed study of the Moon, scientists will have to work on the lunar surface for many, many years with very advanced equipment.

FUNCTIONING IN SPACE

Helping Man to merely survive in the environment of space is difficult enough. Keeping him fit and healthy to do useful work is even more difficult and costly.

Unlike machines, Man requires large quantities of food, water, and air. Of these, water will be the heaviest item. Four men consuming just 7 litres of water a day each will require over 10 tonnes of it in a year. To save on cost, water may have to be re-generated and re-used.

Man's body has to be maintained at a constant atmospheric pressure, and at a temperature ideally around 25°C. He also needs various other

omforts to help him work efficiently. 'hese include proper furnishings, omfortable, hygienic, and colourful nteriors, showers, toilets, kitchens, ntertainment like his favourite ooks and music, and much more. Above all, he needs the company of ellow men, with whom he can get long. While a spacesuit would be dequate to keep him alive, he would not be able to work in it efficiently for a long time. He would thus need a shirtsleeves' environment of the type he would expect in his living room.

All this increases the size, weight, and cost of the spacecraft. On the other hand, as studies in space become increasingly complex, they will either have to be undertaken with Man in the picture, or not undertaken at all.

It is now accepted that there may be no limit to Man's ability to live and work in space. He can adjust to the weightless condition in space in about a week, and then stay there for several months without any adverse effects on his bodily functions or his mental powers.

WHAT WILL MAN DO IN SPACE?

His work will include assembling large structures in orbit; maintaining and repairing satellites; operating space factories to manufacture products that cannot be made on Earth;

The Space Shuttle Orbiter with panels opened to show the Spacelab on board.

studying the behaviour of living creatures like mice and monkeys as well as of Man himself under weightless conditions; observing the most distant parts of the universe; studying the Earth's natural resources like forests, rivers, and mineral wealth; and even exploring the possibilities for tourism in space.

MAN'S ACHIEVEMENTS IN SPACE

Flying in a spacecraft is very different from flying in an airplane. In the former, one faces relatively unfamiliar hazards like a high (or hard) vacuum, weightlessness, deadly radiations, micro-meteoroids, and so on.

So little was known about these hazards before the first manned spaceflight, that reputed medical journals had warned of irreparable damage to the human system owing to weightlessness. For that reason, flights were initially undertaken with mice and monkeys.

After much testing and experimentation, the first manned flight was launched on April 12, 1961 — a single-orbit flight lasting 108 minutes, in the Soviet spacecraft *Vostok 1*. The late

Right: A *Vostok* spacecraft shortly after lift-off. Two of the four booster rockets are seen.

Below: Yuri Gagarin in *Vostok 1* spacecraft.

cosmonaut **Yuri Alekseyevich Gagarin,** then only 27, was its sole occupant. He gained a place for himself in history. He was the first man to overcome the shackles of gravity that had bound mankind to planet Earth for countless centuries. The spacecraft's launch vehicle had an overall length of 38 metres and had four boosters mounted around the central first-stage unit. Each of the five units had a cluster of four rocket motors. In all, the launch vehicle first stage had 32 motors for propulsion and altitude control.

The cone-shaped U.S. *Mercury* spacecraft first went into orbit on February 20, 1962, with astronaut **John H. Glenn, Jr.** in command. Being smaller than *Vostok*, it weighed only 2 tonnes. Its cabin was even more cramped.

There were some interesting parallels between *Vostok* and *Mercury*. Both had a single crew-member who had to wear a cumbersome spacesuit throughout the flight. These spacecraft were primarily designed to place a man into low Earth orbit and to help him **survive** there. The main emphasis was on solving problems like the heat shield design, atmospheric entry, and human tolerance to high acceleration and weightlessness. Weightlessness, in particular, had never before been experienced by Man for an appreciable length of time. The main aim of those missions was to determine how well Man could function in space.

With experience, both the Soviet Union and the United States produced bigger and more advanced spacecraft to enable their crew to perform more useful functions in space. These were the *Voshkod* and the *Gemini*, respectively. Both had a two-member crew and could carry more scientific equipment on board. They also permitted a longer stay in orbit. The *Gemini* had adequate rocket power to *rendezvous* and dock with another spacecraft, the unmanned *Agena*, and also to change its orbital parameters. It was with the *Gemini* that Man could first perform useful work in space. It made spaceflight a comparatively routine occurence

DESTINATION MOON

By far, Man's greatest adventure in space to date was provided by the *Apollo* lunar landing missions. The *Apollo* spacecraft consisted of three components. The conical *Command Module* was that part in which the three-man crew lived and worked while flying between the Earth and the Moon. The *Service Module* was an unmanned vehicle carrying most of the equipment as well as a powerful rocket motor to slow down *Apollo* into orbit around the Moon, and to propel it out of the lunar orbit on its way back to Earth. The small *Lu-*

Apollo 16 Commander John Young at the lunar landing site in the Descartes highlands. In the foreground are the Apollo Lunar Module named *Orion* and the battery-powered rover vehicle.

nar Module ferried two of the astronauts from the lunar orbit to the Moon's surface. A part of it would then return the crew from the surface to link up with the main craft in lunar orbit. The combined *Command Service Module* then returned to Earth after discarding the lunar module. Before atmospheric entry, the service module would also be discarded, and the small command module alone would return the crew to Earth.

Apollo achieved great versatility. Later missions carried an electrically-powered *Lunar Roving Vehicle* to considerably increase the lunar area that could be covered during each mission.

Despite its great achievements, *Apollo* was at best only the Wright biplane of manned lunar flight. Its most obvious shortcoming was that all its components had to be discarded just after one flight. Reusability will have to be an essential feature of vehicles which will be involved in lunar exploration and ex-

ploitation. But *Apollo* was a most efficient vehicle for the technology that was available then.

At one stroke, **Project Apollo** rendered our early findings about the Moon obsolete.

We now know that much of the lunar surface is covered with a fine powdery dust, glass particles, and rock fragments, to a depth of 20 metres, known as the lunar soil or **regolith.** It was probably formed by repeated bombardment of the surface by meteorites of all sizes as well as by cosmic ray particles. The meteorites may have ranged in size from microscopic particles to large chunks of rock several kilometres across.

Lunar rocks are igneous, i.e., they were formed by the cooling of molten lava. Rocks found in the older and more rugged lunar highlands are those that had slowly cooled deep in the lunar interior. Green rocks which were some 5 billion years old were found. They date back to the time when the Moon was formed.

The chemistries of these lunar samples are different from those of the rocks found on Earth. They have no water. They have not been affected by oxygen and have therefore been very well preserved. While both have the same elements, the Moon rocks picked by the *Apollo* astronauts were richer in common elements like aluminium and titanium, as well as in high melting point elements like hafnium and zirconium. On the other hand, low melting point elements like sodium and potassium are rarer in the samples picked. This indicates that the Moon could possibly have been heated at one time to a far higher temperature than the Earth.

With the help of the Apollo Lunar Surface Experiment Packages (ALSEP) left by most expeditions on the lunar surface, studies have been made of lunar vibrations caused by tiny moonquakes and by the impact of meteorites and of the Apollo Lunar Module components that were discarded. These have given valuable information about the Moon's interior. Some of the moonquakes were found to have taken place as much as 800 km. below the surface, that is, at greater depths than the deepest earthquakes.

The result of impacts indicates that the Moon's interior has non-uniform layers like the Earth. The Moon appears to have an outer crust which is about 60 km. thick and a mantle of 800 km. below it. The central core is at least partly molten and probably made of iron. This study also showed that the impacts of meteorites which have heavily cratered the Moon over millions of years, are now fairly rare.

Significantly, while the Moon has no magnetic field, some of the old rocks reveal a preserved magnetism. Probably the Moon once had a magnetic field. In that case, it would

be interesting to know how it was lost. Alternately, the rocks may have derived their magnetism from the early solar magnetic field.

Apollo did not give any conclusive answers regarding the origin of Earth-Moon system. The three main theories are: fission from Earth; condensation of the Earth and the Moon from the same solar nebular cloud of hot gases; and the capture of the Moon by the Earth. At present, fission appears to be the least likely answer; while condensation appears to be the most likely, but only by a narrow margin.

THE SOYUZ-SALYUT COMPLEX

Continuing their manned spaceflight effort in the Earth orbit, the Soviet Union developed the three-man *Soyuz* spacecraft and the *Salyut* manned space laboratory.

A prototype of the *Soyuz* spacecraft.

The 6,575 kg. *Soyuz* spacecraft is made up of three components: the spherical orbital module in which the two or three-man crew can work or relax: the descent module which has the *Soyuz*'s controls and is the only part designed to return to Earth; and the cylindrical instrument module which has instruments and powerful rocket motors to manoeuvre in orbit and to de-orbit for returning to Earth. The instrument module also has two large wing-like solar cell panels to provide electrical power while in orbit.

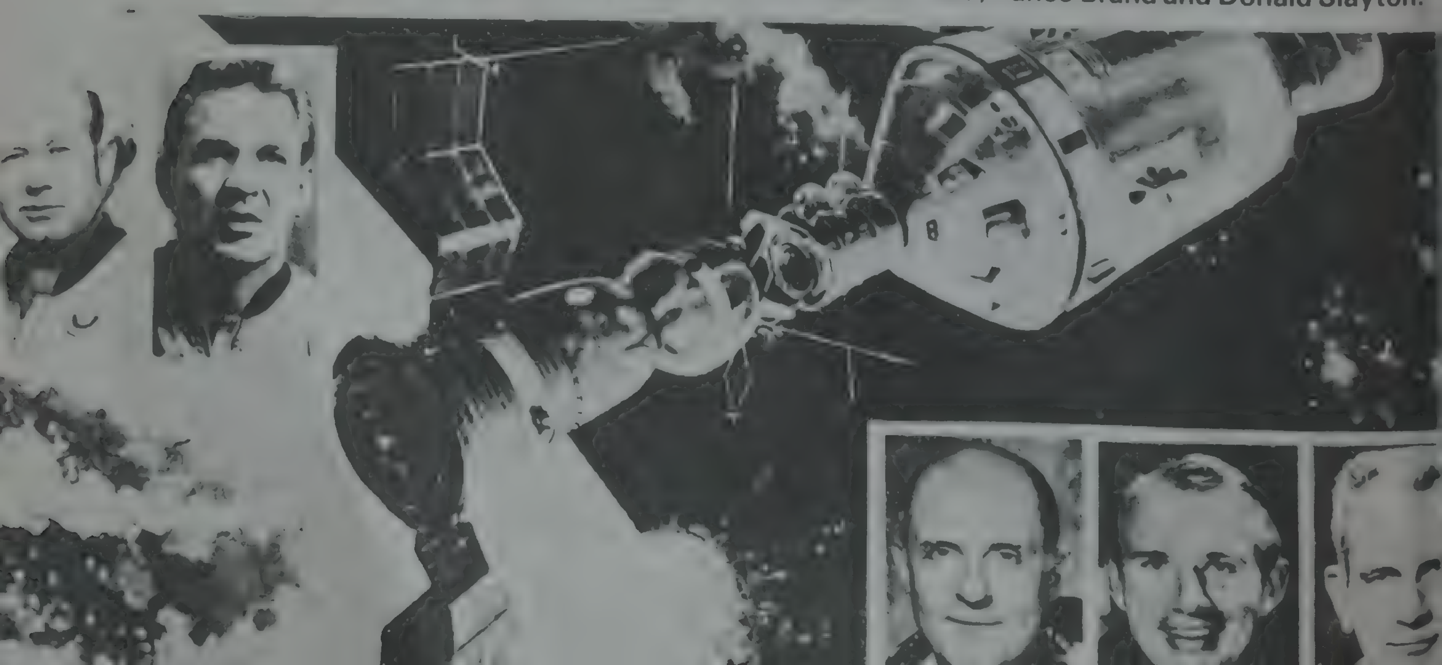
Crew transfer between the orbital module and the descent module is made through a hatch. A second diametrically opposite hatch permits a link-up with another *Soyuz* spacecraft through a unit. Thus two *Soyuz* craft can move together in orbit for a crew transfer and for conducting joint experiments, without the crew having to emerge from the spacecraft.

A most interesting experiment was the joint flight of the U.S. *Apollo* and the Soviet *Soyuz* in the Apollo–Soyuz Test Project. It could lead to greater co-operation in spaceflight between the two countries which are most deeply involved in it.

About three times bigger than the *Soyuz* is the *Salyut* space laboratory which is the forerunner of large and permanent space stations. The *Salyut* consists of a cylindrical transit module which is designed for a link-up with the *Soyuz* transport craft, and the much larger cylindrical work module. Both have room for crew work while in orbit. Beyond these is a sealed module having the control, communications, power supply and life support equipment, followed by the rocket motors and the propellant tanks for manoeuvring it in orbit.

It is interesting to note that for ferry operations between the Earth and *Salyut*, the *Soyuz* craft has only chemical batteries instead of the

The crew of the Soyuz and Apollo spacecraft. Left to right: Pilot Cosmonauts of the USSR, Alexei Leonov and Valeri Kubasov, and the US astronauts, Thomas Stafford, Vance Brand and Donald Slayton.



heavy and cumbersome solar cell panels.

To prolong the duration of *Salyut* missions, the Soviet Union has developed the *Prognoz* (Progress) unmanned transport spacecraft to deliver rocket propellant, experimental equipment, and life-supporting materials like food, water, medicines and clothes. Its design is based on that of *Soyuz* and, being unmanned and non-recoverable, it can carry more cargo than *Soyuz*.

Soviet cosmonauts on prolonged missions on the Soyuz-Salyut space laboratory have been conducting a very wide range of scientific experiments. The fields covered include astronomy, Earth observation from space, space biology and metallurgy.

For Earth observation, *Salyut 6* had on board a camera manufactured by the world-renowned East German company, Karl Zeiss of Jena. While pictures of certain areas were being taken from the space station, pictures of these areas were simultaneously taken from an *Antonov An-30* photographic aircraft flying at an altitude of 8,000 m. At the same time, experts on Earth would take measurements of the soil, the humidity, crop ripeness, and the like. Information from air- and ground-based studies help in the analysis of pictures taken from space. These are particularly useful for locating oil, natural gas and mineral deposits, specially in Siberia. It is claimed that just one photograph could save geologists many months of work from aircraft and through ground surveys. These pictures have also helped to survey water resources and icebergs, and facilitated oceanographic research.

Among the equipment brought to *Salyut 6* by the *Progress* cargo craft were two furnaces named *Splav 10* (Alloy) and *Kristall* (Crystal). The Splav can heat metals to a temperature of about $1{,}100^{\circ}$C. A computer controls the temperature within 5°C. Reflectors concentrate the heat on the sample, while the walls of the furnace do not exceed 40°C. One side of the furnace can be exposed to space by opening an air-lock. Thus the metal sample can be heated under vacuum conditions. 9119

Dissimilar metals like aluminium and tungsten, or copper and indium, were melted together and crystallised under controlled temperatures. The interaction of these metals under weightlessness led to the formation of totally new compounds with unusual properties.

One interesting biological experiment studied the behaviour of tadpoles under weightlessness. One batch, hatched in space, swam in spirals, while those brought from the Earth became disoriented and swam at random. That indicated that the first batch could adapt itself to weightlessness.

Can Man adapt himself entirely to conditions in space? This question

can be answered only when adequate data is available on the behaviour of single-celled living organisms in space, since all organisms including the most complex ones consist of cells. Soviet and French scientists have studied how cells would divide themselves, and thus multiply under the vibrations, accelerations and radiations, and how they would endure weightlessness.

There were also studies of the cosmonauts' body performance under prolonged weightlessness, and the programme of vigorous exercises needed to keep fit in space, and to help adjust rapidly to normal gravity on returning to Earth.

THE FIRST SPACE LABORATORY

By far the biggest, the most impressive, and also the most ingenious manned spacecraft to date was the U.S. *Skylab*. A superb innovation, it consisted of a very spacious and well-equipped orbital laboratory for a crew of three in what was orginally the liquid hydrogen tank of a *Saturn IV* upper stage

Flights to *Skylab* were made in the *Apollo Command Service Module* launched by small *Saturn 1B* vehicles, with *Skylab* itself being launched by the giant *Saturn V*, the largest launch vehicle produced so far. Thus *Skylab* was made from the leftovers of the Apollo programme, and was under taken on a small budget.

What gripped the imagination o professionals and the general publi was the 'rescue' operation undertaken by **Charles (Pete) Conrad, Jr.** and his crew. It was a blood-and-guts saga of heroic dimensions that gained them a place in history, and in legend and folklore. That episode was a befitting climax to the heroic age of space exploration.

An accident during the take-off had torn one of the two large solar cell panels, resulting in the loss of the micro-meteoroid heat shield. To worsen matters, the remaining panel refused to extend, thereby critically reducing the power available on board the space station and endangering the mission. Conrad and his crew extended it after much effort and at great personal risk, and also set up a makeshift shield. Their performance was a conclusive proof of the value of Man in space.

After it was over, they settled down to the numerous scientific experiments as though nothing had really happened.

Some of *Skylab*'s achievements were truly unique and epoch-making. The most remarkable were the studies of the Sun through the *Apollo Telescope Mount*. This resulted in a hundred-fold increase in our knowledge of the only star we can study in detail. The Sun is of considerable interest to Man since it is the

source of all life on Earth, and the only long-term inexhaustible source of energy.

Another major achievement was the observation of the **Comet Kohoutek** (so called after its discoverer) on the last *Skylab* mission. The *Skylab* was the only source of continuous observation of this comet as it flew past the Sun.

Equally impressive results were obtained with the numerous space manufacturing experiments. Large, single crystals of the semiconductor material, indium antimonide, were produced with a surface roughness of only .0000012 cm. It is impossible to achieve such perfection on Earth because of disturbances created in the material by forces like convection.

In another experiment, an attempt was made to weld together two dissimilar metals like aluminium alloy and stainless steel. This proved that the welding of metals in space would pose no major problem. Thus the construction of very large structures in space by welding together basic components should not be difficult.

A stack of plastic detectors designed by scientists at the Tata Institute of Fundamental Research (TIFR), Bombay, to study cosmic rays, was carried on board *Skylab 3*. It was exposed to space conditions for 74 days and gave very valuable information.

Because it was exceptionally spacious, *Skylab* was able to accommodate considerable medical equipment to study Man's performance in space. The results indicate that there may be no limits to Man's ability to survive and function in space, provided he takes adequate physical exercises.

These and other *Skylab* experiments led to an unprecedented enrichment of Man's knowledge. It also gave a faint idea of the shape of things to come when the large space laboratories come into being. Unfortunately, being in a low orbit, *Skylab* entered the Earth's atmosphere some time back and was destroyed.

LOW-COST SPACE TRANSFORMATION

Manned spaceflight has been undertaken on only a limited scale so far, as current launch vehicles are non-recoverable. The reason was that there is no economical way to recover and re-use them. The cost of placing each kilogramme of payload into orbit could be reduced considerably if the launch vehicle is re-used a number of times. Manned spaceflight would then become far more commonplace. The U.S. *Space Shuttle Orbiter* and the planned Soviet *Kosmolyot* belong to this category.

Will the shuttle be considerably more economical than the expendable launch vehicle? When the U.S. *Jupiter C* launched the earliest satellites, they

The complete Space Shuttle Orbiter and boosters at lift-off from a rocket launch pad.

cost almost 10 million rupees per kilogramme placed in low Earth orbit. *Apollo's* giant *Saturn V*, the largest and the most economical launch vehicle made to date, could orbit payloads for only Rs.10,000 per kilogramme. The launch cost with the space shuttle will be further reduced to a fourth.

The cost of the design and assembling of the shuttle will be higher than the earlier expendable, single-shot launch vehicles. It will also be manned, unlike the present launch vehicles. As each space shuttle orbiter (the component that will go into orbit and return to Earth) will make a hundred or more flights, the cost per flight will come down sharply.

The space for experimental payloads to be carried on board the shuttle can be booked for as little as Rs.25,000. There are no rides at present for tourists. Each flight will carry a 30 tonne load at a cost of Rs.175 million per flight. The flights could be made fairly frequent, perhaps once a week.

The space shuttle orbiter is part aircraft and part spacecraft. It has wings like an aircraft but it will be powered by three rocket motors for lift-off as well as for flight in the near-vacuum conditions in space. While it will take off vertically like a rocket, the shuttle will land on a long runway like any aircraft.

About the size of the Indian Airlines' *Boeing 737*, this remarkable vehicle will be able to carry a 30,000 kg. payload in its large cargo bay. It will take off from its launch site on the power of its three liquid propellant rocket motors and two large solid propellant 'boosters'. The propellant for the former is stored in a large cylindrical external tank. When the two solid boosters are exhausted, they are ejected (the term is jettisoned) and gently fall into the sea with the help of parachutes. These 'spent cases' would float on water and

then be recovered by a ship. On being returned to the manufacturer, they will be refurbished.

The shuttle would continue its flight and go into orbit. Once in orbit, the cargo doors would be opened to release the payload. These could be Earth satellites, to be placed in low orbit, or they could be transferred to a higher orbit, (geosynchronous orbit) with the help of small booster rockets.

Additionally, the shuttle crew could repair and maintain payloads already in orbit. At present, payloads have to be extremely reliable to work faultlessly for years. If occasional inspection is possible, they need not be so highly reliable. The cost of their design and manufacture would thus be less than in the past. For major repairs, a satellite could be recovered from orbit and returned to Earth. Payloads of up to 15,000 kg could be brought back in this way.

Shuttle crews could also help assemble very large structures in space. Missions lasting a month will be possible with this vehicle.

When the mission is completed, the shuttle's rocket motors would be used to lessen the speed and enable its descent to Earth. The vehicle would land without any engine power, like a glider, on a runway. But that is not the end of the story. The

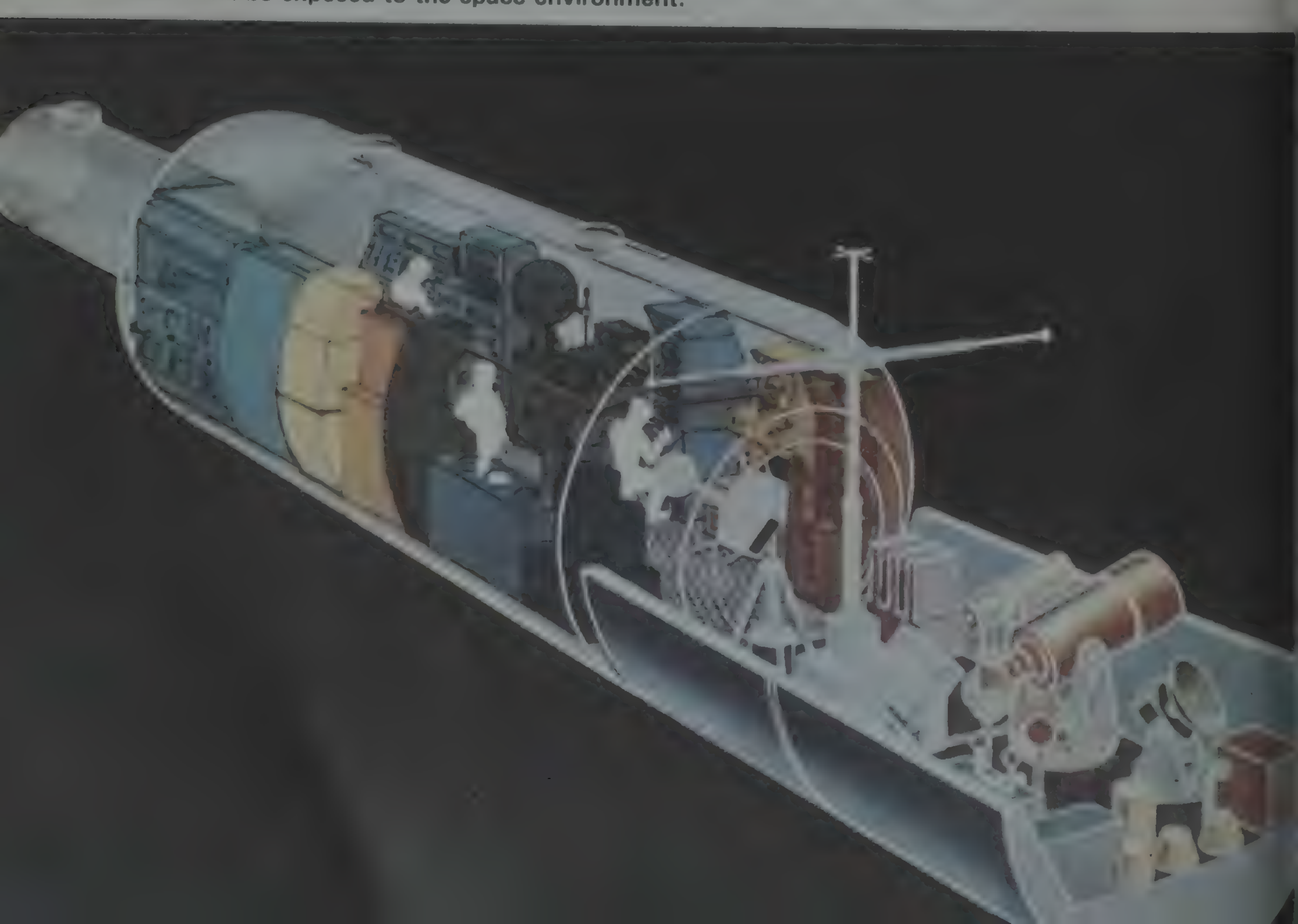
The Shuttle Orbiter spacecraft in orbit around the Earth.

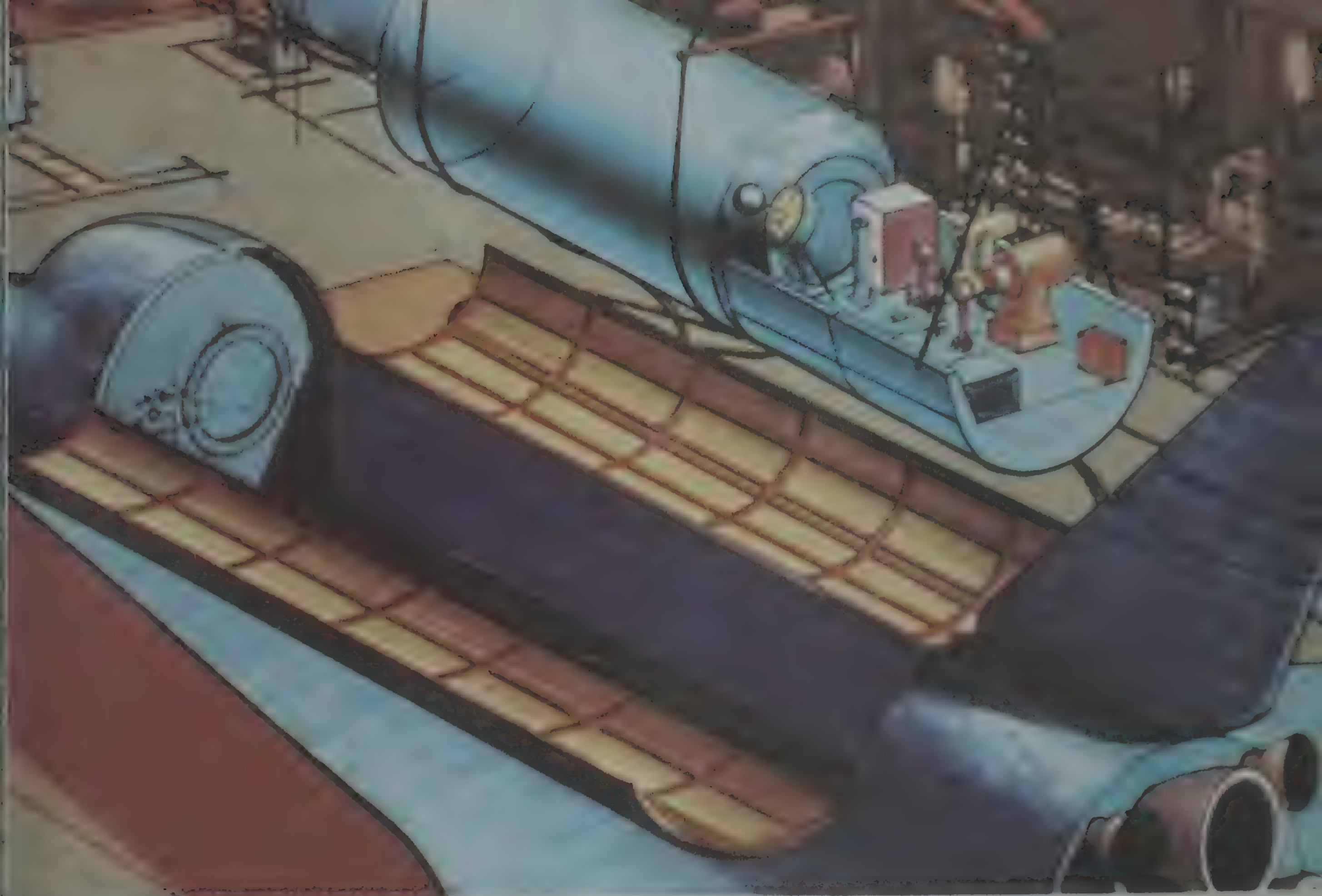
maintenance crew would take over and in a short while, perhaps a week or two, make the vehicle ready for its next flight.

SPACELAB

The first spacecraft to be specifically designed as a well-equipped laboratory in orbit is the European *Spacelab*. It is being designed and produced by the eleven-nation European Space Agency. The *Spacelab* will be carried into Earth orbit by the *Space Shuttle Orbiter*. Unlike the U.S. *Skylab* and the Soviet *Salyut* space stations, the *Spacelab* will have scientists, engineers, and technicians on board instead of astronauts. The crew of up to four would thus be far better qualified for their work. At the same time, they will not require the long, rigorous, and extremely expensive training that is imparted to astronauts. That is because the *Space Shuttle*, which will transport *Spacelab*, will be subjected to far lower accelerations than spacecraft on expendable launch vehicles. Even doddering old men and women will be able to use these facilities, if they are adequately qualified. Even the best of astronauts cannot be very good scientists. The *Spacelab* crew will be appropriately known as

The Spacelab showing the pressurised laboratory where the crew will work, and the instrument pallets which will be exposed to the space environment.





Above: The Spacelab being loaded into the cargo bay of the Space Shuttle Orbiter before being readied for a launch.

Right: Interior of the Spacelab pressurised laboratory.

'payload specialists'.

Another vital difference is that the *Spacelab* can be recovered and re-used several times. After return from orbit, a *Spacelab* would be removed from the *Space Shuttle Orbiter* and re-assembled for the next flight. In the meantime, a second *Spacelab*, kept ready by then, would be flown on the next shuttle service. This would save a lot of time and result in considerable flexibility, as a very

wide range of equipment can be rapidly added or removed from the *Spacelab* for a variety of experiments. It also can change its orbit as required, when carried within the shuttle. Apart from the cylindrical pressurised compartment, the *Spacelab* will have an open platform called a 'pallet' to conduct experiments in the space environment. This can also be varied for each flight according to the requirements.

Scientists at TIFR and the Physical Laboratory (PRL), Ahmedabad, have designed a 'cosmic ray detector'. This will be carried on board the pallet of *Spacelab I* to be launched in 1982. The detector will help study low-energy cosmic radiations reaching Earth from outer space.

A second payload, to study Earth's upper atmosphere, has been designed by scientists at the PRL jointly with the French. This is a measure of the respect that Indian scientists command abroad.

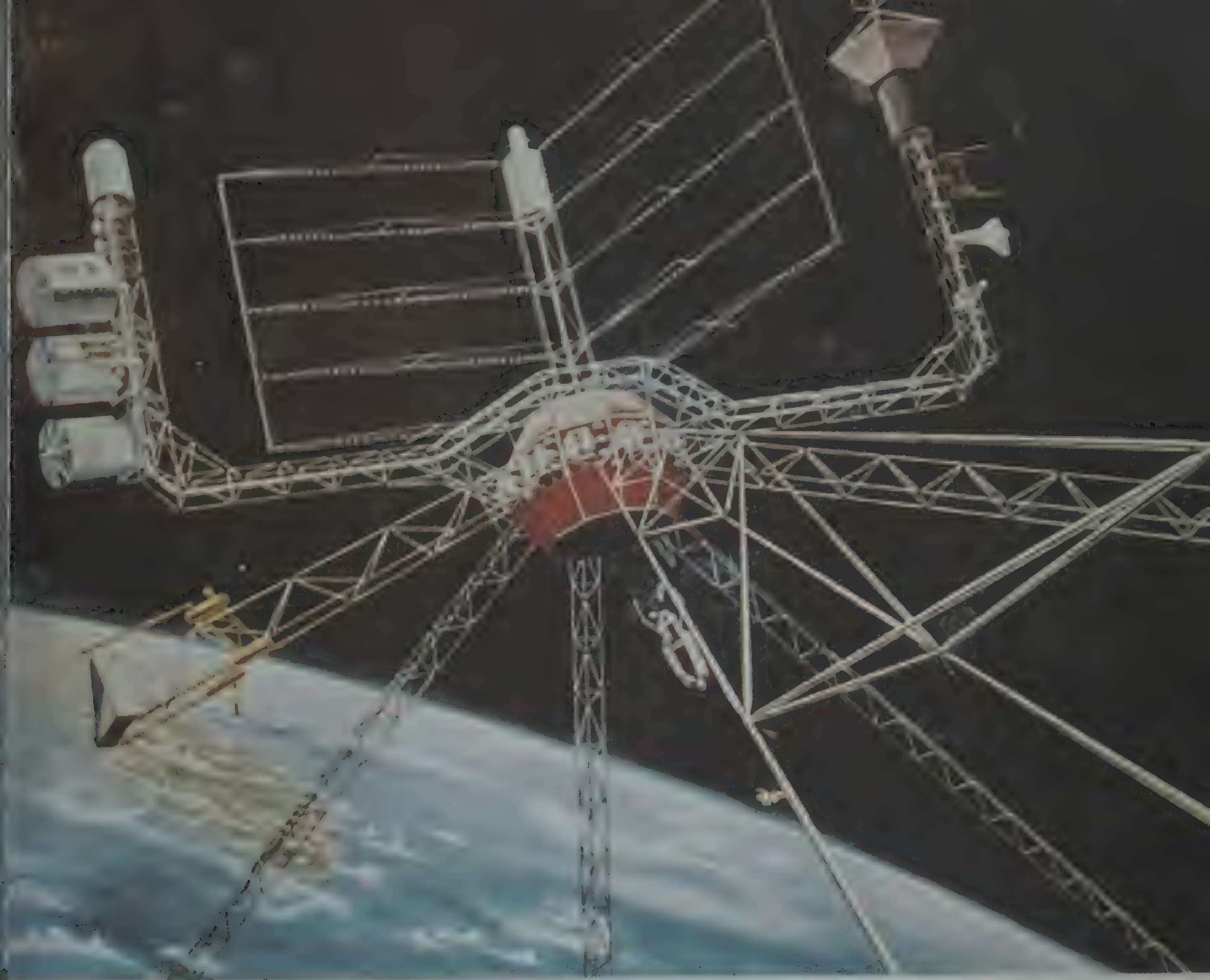
LARGE STRUCTURES IN SPACE

A very important activity for Man in space is the setting up of large structures in Earth orbit. These could be used for solar power satellites, radio-telescopes, the antennae of communications satellites in future and even for large settlements in space. The largest of these would be several kilometres across and would occupy an area greater than that of Bombay.

Space offers some vital advantages for setting up large structures. As they would have no 'weight' in the 'zero-g' environment, they will be made lighter and less strong than structures on Earth. They can be several kilometres in diameter.

It would be impossible to carry such huge, low-density structures into orbit in one piece, even if they were folded. One approach then will be to fabricate them in space from aluminium foil tapes a few millimetres thick and mounted on large reels. Three such tapes could be passed through dies to form hollow tubes. These could be brought to-

A future Solar Power Satellite with about 100 sq.km. of solar cells to convert sunlight into electricity and then beam it to Earth.



A space solar power station using a thermal engine to run an electricity generator.

gether by diagonal braces automatically welded to the tubes to form a continuous lightweight beam several thousand metres long. It would weigh a little more than a kilogramme per metre length on Earth.

Surprisingly, such large-scale construction activities would require few men in space. Astronauts are already studying the techniques for setting up such structures. They do this in a 'weightless' space environment simulated under water in a large pool. The buoyancy or 'lift' of the water balances the pull of gravity.

Among the most ambitious applications of such construction techniques would be the fabrication of **Solar Power Satellites** (SPS). These would occupy an area of several square kilometres, possibly the size of a small city. Each satellite would weigh about 100,000 tonnes. It would be placed in geostationary orbit, 35,880 km. above the city to be served. As the SPS would go round the Earth in

its orbit once in 24 hours, the time taken by the Earth to rotate once on its axis, it would appear to be stationary above that city.

You may have read of **Solar Cells** that directly convert sunlight into electricity. A blanket of several million cells would be laid on the SPS. Together, these cells would generate up to 10,000 megawatts of electricity. That is about ten times more than the electricity to be generated by the largest nuclear power station under construction. It could meet the combined requirements of several major Indian cities.

How would this power be transmitted to Earth? It involves a very interesting technique. The electricity would be converted into **microwaves,** i.e., radio waves of short wavelength, which would be beamed to Earth. On Earth, special equipment would reconvert them into electricity. Science fiction? Well, detailed studies of such stations are already being made. These could come into operation during the lifetime of some of you. And they will be even more impressive than what today's awe-inspiring figures tell us. But then, tomorrow's 'science-fact' will invariably mock at today's science fiction.

Solar cells currently cost about Rs.10 for every watt generated. That price could come down to less than Rs.10 per watt, once the cells are mass-produced. Today, their production is still at the stage of a 'cottage industry'. Similarly, the cost of placing payloads into orbit will also continue to fall, as was explained earlier.

By contrast, the cost of power generation by all other means, particularly nuclear, continues to rise sharply. By the end of this century, the SPS could be producing power at a cheaper price than most other techniques. Indeed, while such power stations in space would cost several thousand million rupees, they would prove to be a very wise investment in the future, specially as oil becomes increasingly scarce.

Lastly, the Sun is an inexhaustible source of power at all times and for all times. And you can get any amount for the asking, once the SPS has been placed in orbit. It is also a fairly non-polluting source of electricity.

SPACE SETTLEMENT

WHICH WOULD BE THE BEST PLACES IN SPACE FOR MAN TO SETTLE?

There are five points where the gravitational pulls of Earth and its Moon would balance each other exactly. An object stationed there would remain in that position at all times, in orbit around the Earth.

Twin space settlements, each ringed with teacup shaped agricultural stations and having manufacturing and power generation facilities at the top. The large rectangular movable mirrors reflect sunlight into the settlements.

These points are known as **Lagrange** One of these points, known as L5, **Points** after the celebrated French physicist, **Joseph Louis Lagrange.** forms an equilateral triangle with the Earth and the Moon. It is one of the most suitable sites being considered.

Chunks of lunar material would be shot towards L5 by powerful linear electric motors called Mass Drivers. The material would have to be accelerated to only about 2.5 km./sec. to escape the Moon's gravitational pull. Space tugs would collect the material and ferry it to L5. The lunar raw materials would be processed in space to provide aluminium titanium, and other elements, as wel as the all-important oxygen. Should i be possible to capture an asteroid, i would form a rich source of iron anc nickel as well as carbon, nitrogen and perhaps some invaluable hydro-gen. (The Moon appears to have nc worthwhile hydrogen in any form. The work may take several years as about a million tonnes of materia would have to be mined from the Moon, hurled into space, anc processed.

Each space settlement, of spherica or cylindrical design, will accommo

Life on board a space settlement, showing some people in the foreground, picnicking by a hill-side stream. As an indication of its size, the bridge in the background has as long a span as the 13.2 km. San Francisco Bay Bridge.

date about 10,000 people, and would be gently rotated to have an artificial gravity field. It can have its own individual terrain with hills and valleys, vegetation (using Moon dust as fertiliser), agriculture, charming little habitations (no high-rise buildings) recreation centres, rivers and lakes, flora and fauna, and a lot more, with the ability to change these from time to time. Alternating with these land areas will be large, full-length glass windows to let in sunlight. Large, hinged panels over windows will swing open and shut on command to simulate the day and night cycle. The settlement will be large enough to manipulate its own weather, including rainfall. Life on board could be really pleasant, human, and attractive, particularly by our present standards.

And why would Man want these space settlements? In part, it could help ease the population problem and give people a better quality of life. In any case, many developed countries have already achieved a zero population growth rate and the trend could become more widespread. More importantly, a wide range of industrial activity could be transferred to space where pollution would not be a problem. Power would be inexhaustible and raw materials would be readily available. These settlements would be virtually self-sustaining and would help rejuvenate our battered home planet, Earth.

MANUFACTURING IN SPACE

Low-cost transportation may lead to the industrial exploitation of space. The environment in space offers several unique conditions that are extremely difficult and costly to duplicate on Earth. These include an almost total weightlessness (zero-g) which can be simulated on Earth only very briefly; a vacuum more perfect than any obtainable in earth-based laboratories; a source of virtually infinite energy from the Sun; perfect sterility; ultra-low temperatures (by shielding from solar radiation and other heat sources); and the like.

Of these, zero-g is the most important. Under this condition, the Earth's gravitational attraction is counterbalanced by a centrifugal force produced by the satellite's rotation around the planet. In practice, the influence of gravity is reduced to about a millionth of that on the Earth's surface but not completely eliminated. Under zero-g, forces like buoyancy and movement in fluids due to heat are at most eliminated. This makes it possible to uniformly mix different solid materials which cannot be done on Earth. Thus, totally new materials with new properties and uses can be produced.

Large industrial companies may some day set up huge factories in space to manufacture products of

greater purity and uniformity than on Earth. They could cover fields like optics, electronics, medicine, metallurgy, ceramics, and many others. The term 'exo-industrialisation' has been applied to the setting up of industries in space. It will bring about an industrial revolution more significant than anything in the past. The stamp 'Made in Space' will some day mark the most sought-after products.

As an interesting example, lead and aluminium can be melted together and mixed under zero-g to form a homogeneous mixture. This would be an excellent alloy for bearings which have very wide applications. On Earth, such an alloy would be very difficult to produce as the heavier lead would separate and sink to the bottom during the re-solidification. Also bearings made under zero-g would be far more perfect spheres than those made on Earth. Similarly, the smelting of materials without a container, by suspending them in an electromagnetic field, eliminates a major source of contamination.

Under zero-g, crystals for electronic equipment can be made bigger and more perfect. Large, pure, and exotically-coloured crystals would fetch fancy prices as jewellery. Medical products like vaccines, proteins, and enzymes can be made far more homogeneous under this condition and would thus be more effective for treatment. Eurokinase is a very useful drug in preventing blood clots in people prone to heart attacks. On Earth, gravity prevents the effective separation of cells that bear eurokinase from others. Under zero-g, they can be easily separated by using electric fields. This drug could save thousands of lives some day.

Any medical preparation that is produced in the highly sterile space environment is sure to be free from bacterial contamination. Ultra-violet radiation in space would kill most bacteria. On Earth, most of these radiations, dangerous to all life, are filtered by the atmosphere, particularly by the ozone layer.

While much of the exo-industrial effort will be made in Earth orbit, Man will have to go to the Moon or even deeper in space in search of raw materials. Most of the minerals and ores on Earth will not last long. Moreover, the cost of transportation from Earth would be very high because of the very high escape velocity that would have to be provided. Lunar escape velocity is only about a fifth of this.

Asteroids, believed to be the remains of a planet that disintegrated millions of years ago, are known to be very rich in metals like iron and nickel. Some of them like **Taurus** are only about a kilometre across, and at times pass close to the Earth. Such asteroids could be 'captured' by deflecting them into orbit around the Earth with the help of powerful

nuclear rockets. They can then be mined at leisure. It is estimated that one asteroid could give enough nickel for the next 200 years, and steel for about 15 years. 9119

LARGE SPACE STATIONS

Studies of supreme importance in many fields of science can be undertaken in large space stations. The most elementary of these will be cylindrical structures for scientists to live and work in space. As the demand for capacity increases, other similar cylinders, called 'modules' could be added to form space stations of any size. Ultimately, hundreds of men could work in them at a time. These personnel would be able to return to Earth every few months in the course of their work.

And what kind of work would scientists be involved in the space stations? They could study the winds, cloud formations, temperatures, sea conditions, etc. on Earth over long periods to enable a better understanding of weather. Such studies could help us predict the weather accurately and, perhaps, control it. The benefits of that to mankind would surely be enormous. They could make an overall study of the world's forests, wildlife, fresh water resources, snow cover, mountains, mineral wealth, fisheries, etc. That would give a clearer idea of the world's renewable and non-renewable resources and how best they should be used.

Studies of agricultural lands would indicate the best times for sowing, crop maturity, optimum yield, and also warn farmers of pest attacks and the like well before agriculturists on

A Shuttle Orbiter readying a Large Space Telescope for placing into orbit.

Earth would come to know them.

Research on the behaviour of cells under weightlessness could help in the fight against cancer. Further, by using live animals and man as a subject, we could study the effects of weightlessness on living organisms and Man's ability to adapt to it.

Powerful space telescopes that can pick up X-ray, ultra-violet, infra-red, and the visible radiations of stars would reveal more about the birth, evolution, and death of stars, the little-understood energy source of pulsars and quasars, and many other mysteries of the universe. They could provide a better understanding of the 'black holes'—massive, collapsed stars of such dense matter that the Earth, at that density, would be no bigger than a ping-pong ball.

Astronomers could some day penetrate to the outer limits of the Universe, if there are such limits. Their instruments will take them not only through space but through time. This is because the light that we receive from the most distant galaxies, billions of light years away, must have started its outward journey billions of years ago. A light year is the distance that light travels in a year. It is the only convenient way to measure astronomical distances with meaningful figures. Some day these studies may conclusively prove or disprove that the Universe did indeed begin with a big bang. The best way to make these astronomical studies is from space, above the obstructing blanket of the Earth's atmosphere.

TOURISM IN SPACE

It is almost certain that when large space stations are established, they will be visited by tourists. Space is the new frontier for tourists who have already explored every nook and corner of the Earth. Those who always look forward to visiting new places and undergoing new experiences are sure to go beyond the Earth's orbit to the Moon and perhaps also to the planets of our Solar System.

Let no one consider such ventures to be frivolous. Travel enriches the human spirit and widens our all-too-narrow horizons. Space tourism will give Man a clearer understanding of his place in creation. Further, when two Earthmen meet each other on the edge of a lunar crater or in the deserts of Mars, they will not be just another American, German or Arab, but another man from the home planet Earth.

It was our proud privilege to have witnessed the birth of the space age. Those who had doubted the value of space flight are now experiencing a change of heart. The words of the space pioneer, **Dr.Wernher von Braun,** seem prophetic: 'We have taken mankind to the threshold of space. The road to the stars is now open.'

THE FIRST SPACE SHUTTLE

With the successful launching of the first Space Shuttle, Columbia, from the Kennedy Space Centre, at 17:30 I.S.T. on 12th April, 1981 (exactly 20 years after the first man, Yuri Gagarin, went into Space to orbit round the Earth), the world has entered into a new and exciting era in manned space exploration. Columbia

John W. Young in the Space Shuttle.

orbited the Earth 36 times and landed safely on the large Rogers dry lake bed at Edward air force base in California's Mojave desert, after a 54 hours and 27 minutes stay in space. The Space Shuttle, which had been a dream of space scientists for over three decades has become a reality. The cost of the programme so far has been about U.S. $ 10 billion.

The shuttle was piloted by John W. Young and Robert Crippen. John Young had travelled in space four times earlier and was one of the astronauts who had been to the Moon.

Those who had witnessed flights of the Saturn V-Apollo spacecraft a decade earlier remember its slow, graceful lift-offs. From these huge vehicles, only the little Apollo Command-Service modules could be recovered on Earth, though not re-used. Columbia is different in both respects. Every single component is re-usable, except the massive liquid propellant booster. In addition, owing to the two powerful solid propellant boosters, the lift-off was more rapid, and it flashed past its huge launch tower in just 7 seconds. The roar from its rocket motors was also much greater.

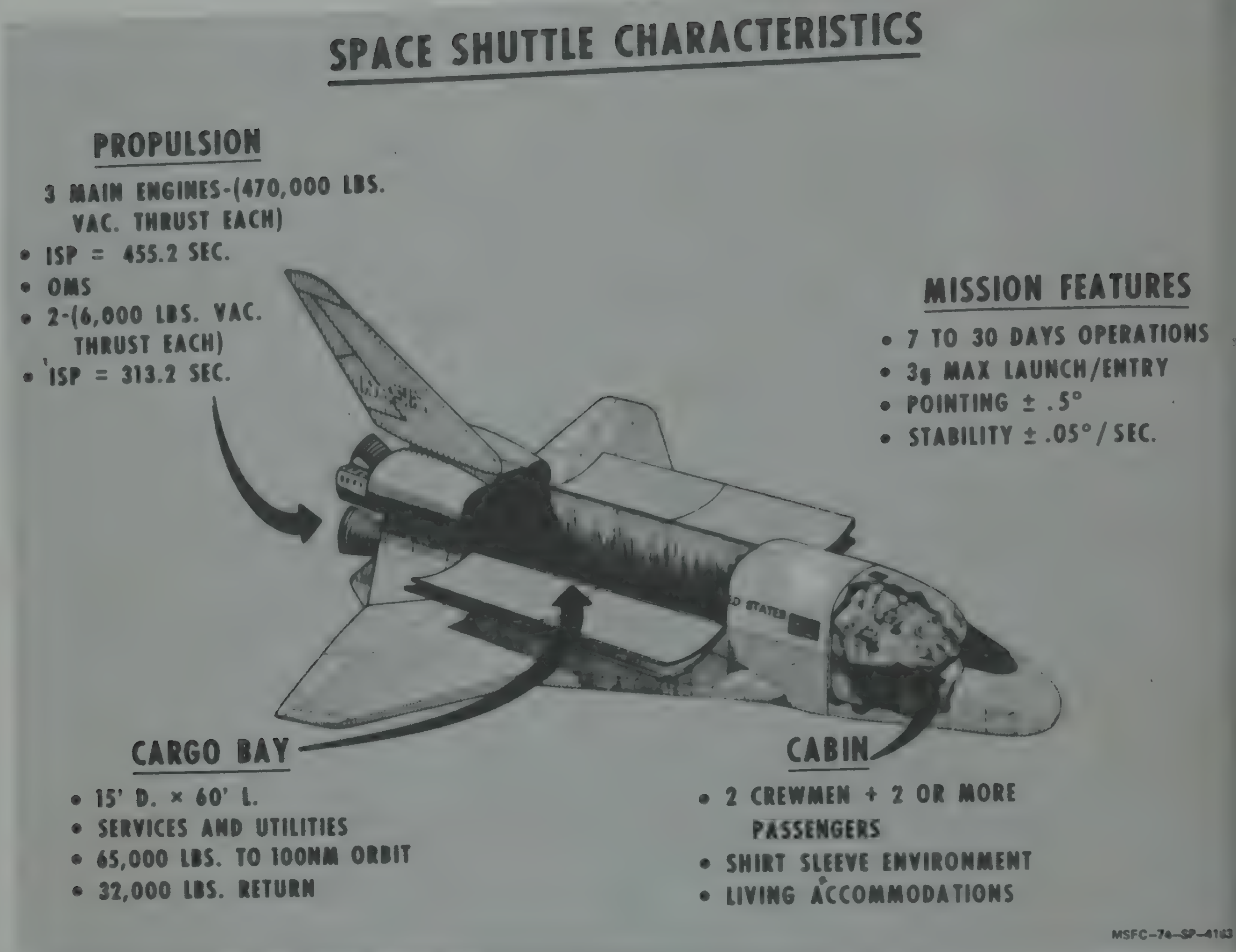
About 2 minutes and 5 seconds after the lift-off, the two solid propellant boosters were jettisonned. By that time, Columbia was on its way out over the Atlantic Ocean. The boosters, which were gently brought down by parachutes, were picked up by ships and returned for re-use. About 8½ minutes after the lift-off

the large liquid propellant tank was released, and discarded into the Atlantic below. Only 11 minutes after the lift-off, Columbia was in orbit, 210 kilometres above Earth. Later, using its own rocket power, it rose to 240 kilometres.

The shuttle orbiter flew 'upside down' so as to have a continuous view of the Earth. Among the tests performed was the opening of the 20 metre long cargo bay doors, and shutting them tight again. Had they failed to close, the crew would have had to don their spacesuits, emerge from the spacecraft, and shut them manually. Otherwise, the return flight to Earth would have been endangered.

On its return, the rockets of Columbia were fired to slow down the speed of the Shuttle from about 28,000 km. per hour to 25,750 km. per hour. This brought it down to denser layers of the Earth's atmosphere. Once there, the atmosphere's drag slowed it down further.

In the final stage of the flight, Columbia glided at over 375 km. per hour to a smooth landing. The approach and landing had to be perfect as there was no way to go around a second time.



It should be remembered that during its return journey Columbia was unassisted by any engine power—just like a glider.

THE COMPOSITION OF THE SPACE SHUTTLE

WHAT IS A SPACE SHUTTLE? AND WHAT IS SO UNIQUE ABOUT IT?

The Space Shuttle is a re-usable spacecraft, unlike the conventional spacecraft which lose their operational value after one mission. The shuttle takes off like a rocket and after completing its mission in space lands like an airplane; to be more precise, like a glider on a special, long runway. The Space Shuttle can be re-used for about a hundred times.

The Space Shuttle system consists of three parts, (1) The Orbiter (2) The solid propellant booster rockets (3) liquid propellant tank. The solid propellant rockets are separated from the Shuttle at an altitude of 44 kilometres. Further up in space the liquid propellant tank is also discarded and dropped into the ocean.

A Shuttle would normally stay in orbit for periods ranging from a week to about a month before returning to Earth. The re-entry is the most crucial part of the flight when the outer surface of the Shuttle is heated to red hot temperatures. In order to protect the vehicle during re-entry, the surface of the Columbia Shuttle was insulated by 30,922 small heat-resistant special fibrous silica tiles. (A few of these, however, fell off as the spacecraft took off.) The temperature of the outer surface of the Space Shuttle rises to about 1500 degree centigrade.

USES OF SPACE SHUTTLE

The Space Shuttle has been devised mainly to carry a pressurised laboratory where scientists and astronauts can work in the so called shirt sleeves environment. Researches in astronomy, astrophysics, solar physics, biological and medical sciences are planned to be carried out in various Shuttle missions.

The Shuttle can also be used as a service station in space for spacecraft in trouble. Normally in the event of any major defect in a spacecraft, it is difficult to rectify the errors by ground commands but with the help of the Shuttle the Spacecraft can be brought back to Earth for repair and placed again in orbit.

With the help of the Shuttle, equipment can be placed in Earth orbit for a long time and can be later retrieved by a second Shuttle. Experiments which need a long exposure time in space can be conducted by such Shuttle missions.

INDIA AND SPACE SHUTTLE

India will be greatly benefited by the Space Shuttle. India's communications satellites—INSAT—can be placed in space using the Shuttle. Launching our communications and other satellites using the Shuttle will reduce our costs substantially. Indian scientists are fabricating a Cosmic Ray Detector system to be placed in the Space Shuttle—Spacelab III.

THE FUTURE

One of the futuristic plans for the Space Shuttle is to use it in building space colonies where men can work and live for prolonged periods of time. The equipment can be transported into space using Shuttles. The astronauts would be literally building the space colonies using pre-fabricated materials. A large array of solar collectors can also be built to tap solar energy which can be transmitted to earth in the form of microwaves. To sum up in the words of the former NASA administrator, Robert Froesch, 'We are now at the threshold of a new capability to investigate the Universe.'

GLOSSARY

Aerospace: This word is derived from *aeronautics* and *space*, and refers to the area of possible flight operations for unmanned satellites as well as for manned spacecraft.

Asteroids: The large number of small celestial bodies, most of them only a few kilometres across, revolving in orbit around the Sun. Most of the asteroids are between the orbits of Mars and Jupiter. This region is called the Asteroid Belt.

Astronaut: One who flies in the space environment. Same as cosmonaut (Russian).

Astronautics: Science of space flight.

Astronomical unit: An astronomical measure of distance for closer objects, primarily within our solar system. It is the average distance between the Sun and Earth — about 149.6 million km. Abbreviation A.U.

Atmosphere: The layer of gases surrounding the Earth, or any other planet, star or other celestial bodies.

Billion: One thousand million in U.S.A. Elsewhere a million million.

Booster: A rocket, usually expendable, used as the first stage of a launch vehicle, to impart initial acceleration for lift-off from the Earth.

Celestial object: Any natural body in space like a star, planet, comet, asteroid, etc.

Centrifugal force: When an object is constrained to move in a curved path it reacts with a force directed away from the centre of curvature of the path. This force is called the centrifugal force. For a satellite in orbit, the gravitational force of attraction and the centrifugal force balance each other.

Computer: An electronic machine to undertake mathematical calculations, store information, and perform a range of other functions.

Combustion chamber: That part of the rocket motor where the fuel and oxidant are ignited and burnt, particularly for liquid propellant engines.

Command Module: That part of a manned spacecraft which has the main controls.

Cosmic rays: Highly penetrating rays from outer space. When cosmic rays enter the Earth's upper atmosphere, they contain mainly protons and small quantities of helium and other particles. Collision with atmospheric gas molecules results in many kinds of other particles, e.g. neutrons, mesons, and hyperons.

Cosmonaut: Same as astronaut. This term is used mainly for Soviet and Eastern European astronauts, and is derived from 'cosmos' meaning universe.

Docking: The mechanical linking together of two or more spacecraft, while in space, after they have achieved a rendezvous or close approach.

Exobiology: The study of life on planets and other celestial bodies, other than the Earth.

Expendable launch vehicle: All launch vehicles used to date have been 'expendable', i.e. as the propellant in each stage is used up, it is discarded, falls to Earth, and is destroyed. By contrast, re-usable vehicles can be recovered and re-used after each flight. The first of these will be the Space Shuttle Orbiter.

Extravehicular activity (EVA): Activity undertaken by an astronaut outside the protective environment of his spacecraft, effectively in the space environment.

Geo: A prefix for things pertaining to Earth, e.g. geocentric orbit, geomagnetism, geology, and geography.

tationary orbit: An equatorial orbit in which an Earth satellite moves from west to east at such a height and velocity that it takes the same time to go once around the Earth as the Earth takes to turn once on its axis. Such a satellite thus appears to remain stationary over a particular point on Earth.

ravity (Gravitation): The force of attraction between two bodies which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

aunch pad: A platform on which a rocket is mounted vertically for launching. It usually has all the necessary facilities for maintenance of the vehicle as well as the wide range of equipment on board.

Launch vehicle: A rocket-propelled vehicle used to launch a payload into space. This term is usually used to mean satellite or spacecraft launch vehicle. Vehicles used to carry payloads to low altitudes, are called sounding rockets.

Light year: An astronomical measure of distance, being the distance travelled by light in a year. This is equal to about 9.46×10^{12}km.

Lift-off: The vertical take-off of a rocket vehicle from its launch pad.

Liquid propellant rocket: A rocket in which both the fuel (like kerosene, ammonia, hydrazine, etc.) and the oxidant, also called oxidiser (like liquid oxygen, nitrogen tetroxide, hydrogen peroxide, etc.), are liquids.

Micrometeoroid: Small particles of matter that move through space at considerable speed and could thus pose a threat to manned spacecraft. Actually, they have been found to pose less of a hazard than had been believed at one time. Those micrometeoroids that survive the passage through the Earth's atmosphere and reach the Earth's surface, are called micrometeorites.

Newton: The force required to give a mass of one kg. an acceleration of 1m./second^2.

Oceanography: Geography of the ocean dealing with its natural features.

Orbit: The continuous path of a body around a large celestial body like a star or a planet, exclusively under the influence of gravity. Such an orbit follows a closed elliptical path.

Orbital period: Time taken by an orbiting body to complete one orbit.

Outer space: Space beyond the Earth's effective atmosphere.

Payload: The net weight (distinct from the weight of the carrier rocket) which is carried into space.

Pressure suit: The suit and helmet that are worn by an astronaut while in the space environment. It provides adequate body pressure as well as a breathable atmosphere.

Propellant: The solid or liquid working substances in a rocket which are subjected to combustion in a rocket motoı or engine. The gaseous products of combustion are then exhausted to produce the thrust that propels the rocket vehicle.

Pulsar: A peculiar radio source, emitting regular and rapid pulses of radio energy. First detected in 1967.

Quasars: The most distant and most luminous bodies known. So far more than 200 have been identified. The source of their intense radiations is not known.

Radiation: Dissemination of energy from a source in the form of waves of any wavelength. The term is applied to electromagnetic waves, X-rays, gamma rays, etc., and also to emitted particles (α and β, protons, neutrons, etc.) Light is a form of radiation. Some forms of radiation are lethal to man in space if he is unprotected.

Radiotelescope: Any type of receiver of cosmic radio signals.

Recovery: The procedure for the safe return to Earth from orbit of a satellite or spacecraft.

Re-entry: The entry of a spacecraft into the Earth's atmosphere. A more correct term is atmospheric entry.

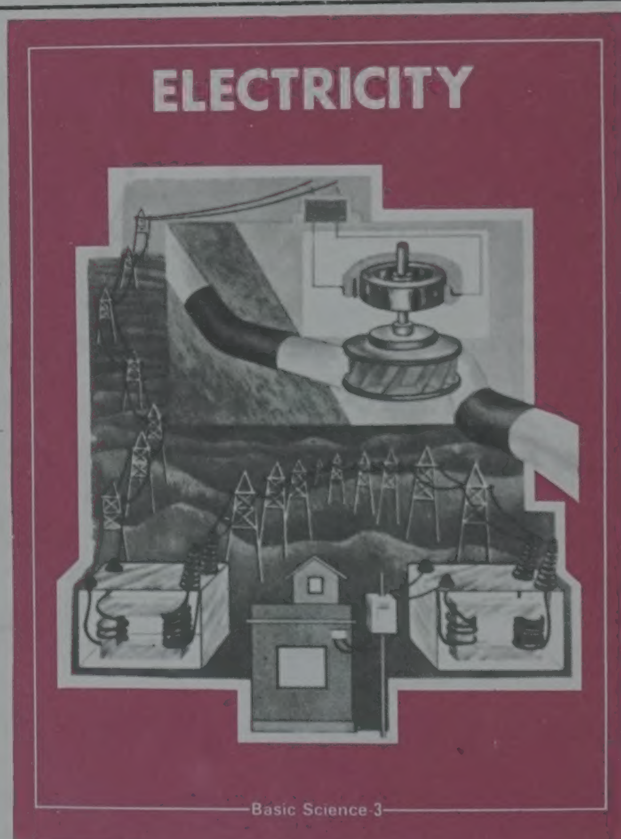
Rendezvous: The coming together of two or more spacecraft in orbit.

Satellite: A natural or man-made object that rotates around a much larger body, known as the primary. Thus the Moon is a natural satellite of Earth. Man-made satellites have been placed into orbit around Earth, Moon, other planets, as well as the Sun. Manned satellites are usually called spacecraft. So are artificial satellites of the Sun and other planets.

Solar cell: Photoelectric cell using silicon, which collects photons from the Sun's radiations and converts the solar energy into electrical energy.

Space suit: A suit for use in space or on the Moon or on a planet. It is designed to provide pressurised oxygen supply, the right temperature and an arrangement for the purification of exhaled gases.

Weightlessness: A condition under which a satellite or spacecraft is not subjected to any appreciable acceleration, whether due to gravity or any other force. Thus, for a satellite in orbit around a primary like Earth, the force of gravitational attraction is counterbalanced by the centrifugal force generated by its movement around the primary. The satellite is then said to be under a condition of weightlessness or near zero-g.



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